Quebec Overpass Collapse Juxtaposed to Deteriorating Infrastructure in Canada

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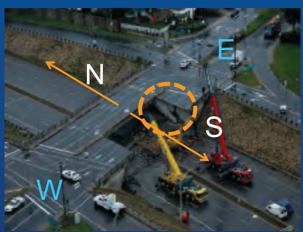
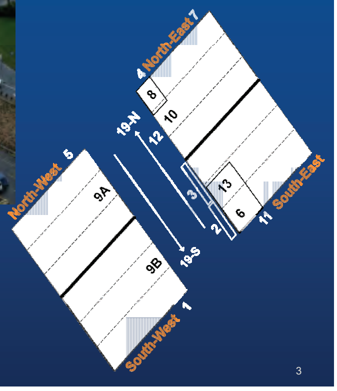




Chronology:

- September 30, 2006 - Collapse of the south-east side of the overpass;
- October 1, 2006 – Beginning of the police investigation;
- October 6, 2006 – Appointment of the commissioners (Johnson, Nicolet & Couture);
- October 18, 2007 – Publication of the report.

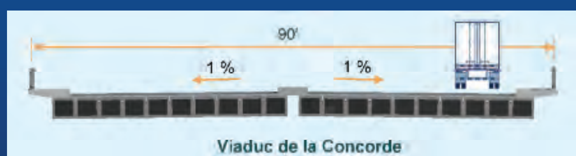
Main characteristics of the structure

Central span – 90 feet

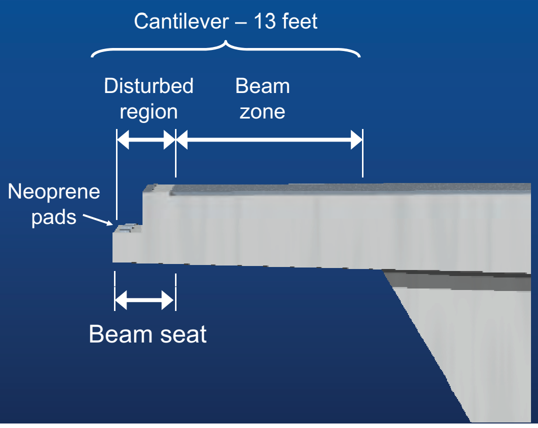
West abutment

East abutment

Main Characteristics of the Structure



Characteristics of the Structure



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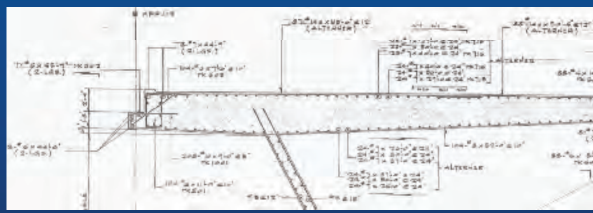
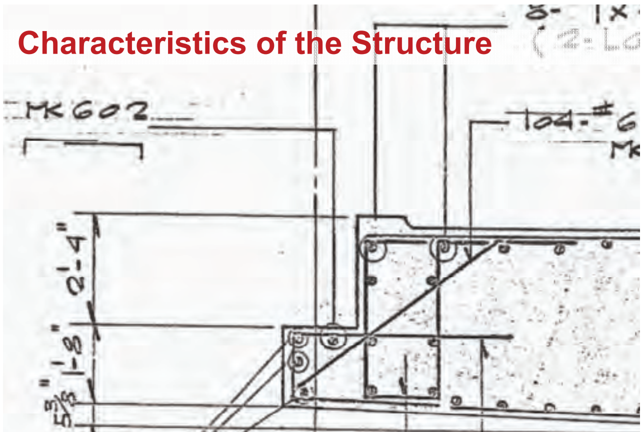


Characteristics of the Structure



Extrait du feuillet 29, Plans de Desjardins Sauriol et Associés
Viaduc de la Concorde

Concrete Mixture Design

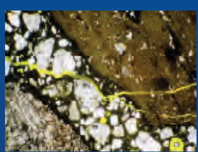
TABLEAU 8-4.1

Affaissement 3" ± ½" sauf classe D Pourcentage d'air occlus en volume: ± 1%		Béton coulé dans l'air et exposé à: air			eau			Eau salée sels dégivrants			Béton coulé dans l'eau
Gros agrégats	pouce	1 ½	3/4	½	1 ½	3/4	½	1 ½	3/4	½	1 ½
Rapport maximum eau/ciment		.56	.56	.56	.50	.50	.50	.45	.45	.45	.45
Ciment minimum	lb	480	525	570	525	570	610	570	610	655	700
Air occlus	%	4.5	6	7	4.5	6	7	5	6.5	7.5	
Type		A			B			C			D

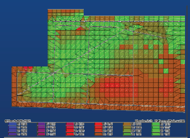
Dans ce projet, seul le type d'exposition A s'applique à toutes les charpentes.

A Multi-Faceted Investigation

On-Site Studies



Materials Analyses



Structural Analyses

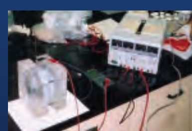
Review of Documents

Materials – A 3-Step Investigation

Phase 1 – On-Site

Phase 2 – Storage Site

Phase 3 – Laboratory Experiments



Phase 1
In-situ operations

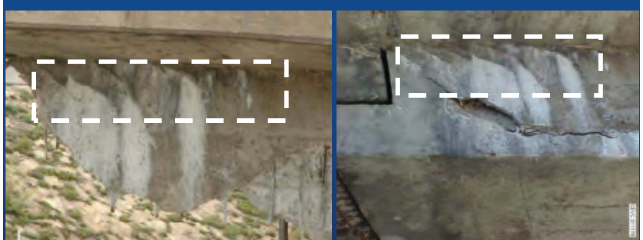
In-Situ Observations

Rupture surface – South-East corner

In-situ observations

Rupture surface – South-East corner

In-situ observations



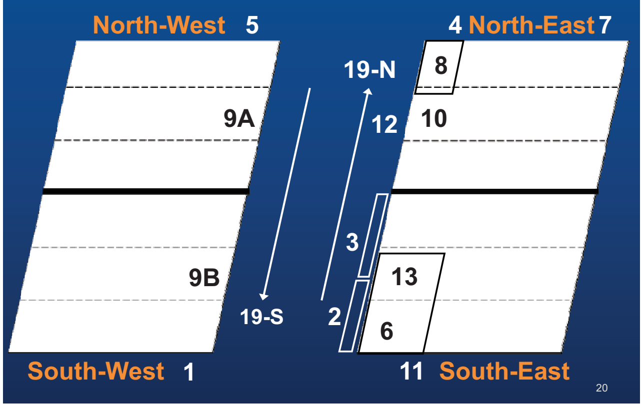
Right after the collapse **Before the collapse**

South-East corner

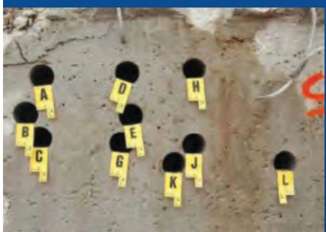
In-situ observations

North-East corner

Coring Operations



Coring operations



- To characterize concrete
- To detect the presence of a cracking plane

Coring operations

Core A – Site 8

Core hole A
Site 8

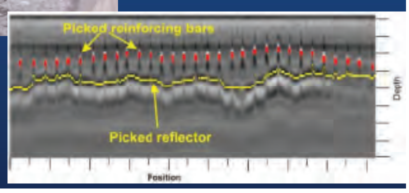
Extraction of Large Pieces

South-East corner

North-East corner

NDT Measurements using Radar

- Both abutments
- Top surface



Phase 2
Operations at the storage site

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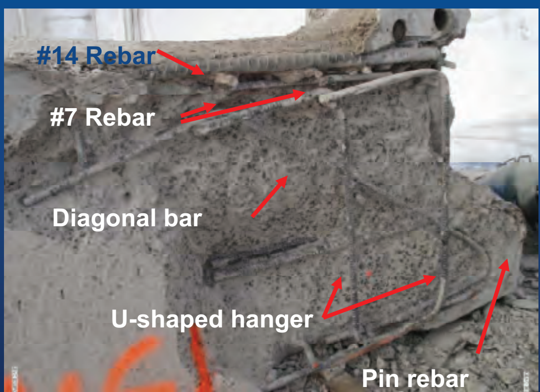
Reinforcing Bar Location - East



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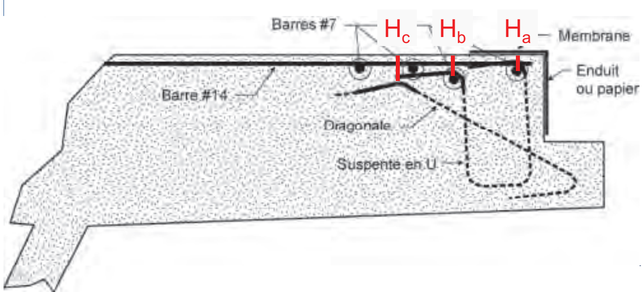
Reinforcing Bar Location - West



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The 3 Main Causes of the Collapse:

1. Improper rebars installation during construction

The incorrect placement of the U-shaped hangers and diagonal bars created a zone of weakness that extended deep inside the thick slab.

Concrete Degradation – South-East Corner

Phase 3
Material Characterization

Concrete Characterization

Main objectives

- To characterize the properties of concrete (on cores extracted from « sound » areas)
- To identify the cause(s) of the concrete degradation along the rupture plane

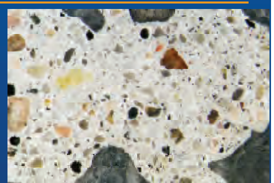
Compressive Strength Determination
(CSA A23.2-9C)

Site	Cores	Orientation	Results
1	3	Horizontal	28,7 MPa
2	2	Vertical	28,2 MPa
3	3	Vertical	31,3 MPa
4	3	Horizontal	40,5 MPa
5	3	Horizontal	31,3 MPa
7	3	Horizontal	27,3 MPa
9A	3	Vertical	27,7 MPa
9B	3	Vertical	30,7 MPa
10	3	Vertical	35,1 MPa
11	3	Horizontal	29,4 MPa
13	2	Vertical	31,6 MPa
Girders	6	Variable	51,4 MPa

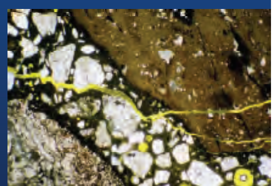
Compression
Mean: 31,1 MPa
Spec. = 27,8 MPa at 28 days

Petrographic Examination

- Porous concrete (W/C ≈ 0,55)
- Well hydrated concrete
- Very few microcracks
- No signs of ASR

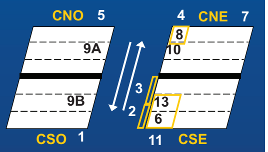


Frost attack was identified as the main cause of concrete degradation at the vicinity of the rupture plane.



Air-Void Characteristics

Site	Air Cont. (%)	Spec. surface(m m-1)	Spacing factor (µm)
1	3,8	14,6	368
2	4,7	10,1	513
3	6,3	12,8	351
4	2,0	11,0	683
5	5,6	11,2	411
7	4,4	13,4	377
9A	5,1	16,0	294
10	5,2	16,1	295
11	9,1	10,7	317
13	5,8	12,8	356



Air content (%)
Mean: 5,2
Standard dev.: 1,8

Specific surface (mm^{-1})
Mean: 12,9
Standard dev.: 2,2

Spacing factor (µm)
Mean: 397 > 230
Standard dev.: 119

Scaling Resistance

Permissible limit
0.5 kg/m² after 56 cycles

Results
7 kg/m² after 21 cycles

The 3 Main Causes of the Collapse:

2. Low quality of concrete

The concrete used for the construction of the abutments did not have the necessary characteristics to resist freezing and thawing cycles in presence of de-icing chemicals.

The 3 Main Causes of the Collapse:

3. Improper rebar detailing during design

In the structure as designed, the concentration of numerous rebars on the same plane in the upper part of the abutment created a plane of weakness where horizontal cracking could occur.

The 3 Main Causes of the Collapse

1. Improper rebars installation during construction
2. Low quality of concrete
3. Improper rebar detailing during design

Influence of the Collapse:

All structures built at that time using the same structural system were all taken out of service….

Trial of the Collapse

Although it was a police investigation, no one was found criminally responsible..

Compensation for the Victims

Compensation was paid to the victims of the collapse. Total compensation for the survivors of the 5 deceased was about $1.5 million.

Responsibility of Road administrators

Significant new funding is now available for periodic condition assessment, health monitoring and research.

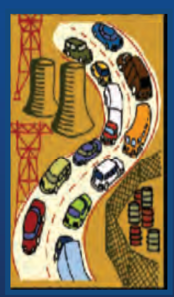
Required Future Research

Development of advanced tools for health monitoring and condition assessment of structure.

Creation of a strategic network on this topic.

Infrastructure Crisis in Canada

Civil Infrastructure

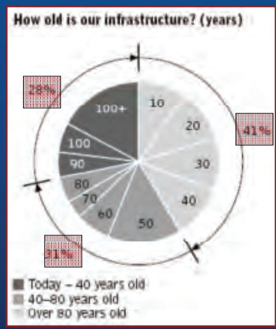


- Aviation
- Bridges
- Dams
- Drinking Water
- Hazardous Wastes
- Roads
- Energy
- Schools
- Navigation Waterways
- Public Parks and Recreation
- Security
- Solid Waste
- Transit
- Waste Water

Infrastructure Deficit

- Infrastructure Deficit Hypothesis: A decline in the public capital formation (i.e. infrastructure) lowers private sector productivity and, therefore, lowers a nation's real income and weaken its competitiveness.

Infrastructure in Canada



59% of Canada's infrastructure is more than 40 years old

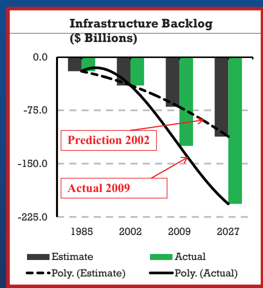
As per Statistics Canada, 37 years is the expected average life of a structure in Canada.

Infrastructure in Canada

- There are approximately 10,000 deficient bridges with a total repair /strengthening cost of $44 billion.
- There are 4000 parking garages needing immediate attention.

Infrastructure in Canada

- Canada's current infrastructure deficit is $125 billion (and growing annually by $2 billion), which is 6-10 times the level of all annual government infrastructure budget combined.



Prediction in 2002 which has already proven to be an underestimation

Why are we in such dire straits?

- Deterioration and aging of structural systems due to weather, fatigue, pollution, structural settlement and now global warming;
- Construction mistakes;
- Code changes (structural dynamics, seismic design, etc.);
- Loading changes; and
- Functional Obsolesce.

Influence of Global Warming on Concrete Structures

- Increase in atmospheric CO_2 levels from 370 ppm to 1000 ppm
  - Increased Corrosion Rates
  - Increased Carbonation
- Increase in temperature by over 5^0C
  - Increased Shrinkage
  - Porous Microstructure and High Permeability
  - Increased Corrosion Rates
- Increased Water Levels
  - Increased Saturation
  - Greater Scour

Scour

Detection and Measurement Needs

- Damage
  - Impact
  - Cracking
  - Fatigue
  - Overload
  - Scour
  - Seismic
  - Settlement
  - Foundation
  - Inoperative bearings
  - Movement/Lack of movement
- Deterioration
  - Corrosion
  - Water absorption
  - Loss of prestress
  - Unintended structural behavior
  - Soil stiffness

NDT for Detection of Damage and Deterioration

- Damage
  - Cracking
  - Fatigue
  - Excessive Displacements/ Settlement
  - Scour
  - Foundation Issues
- Deterioration
  - Rebar Corrosion
  - Water absorption
  - AAR/Freeze-Thaw/Scaling
  - Overall integrity

Limitations of Current Inspections

- Condition states still based solely upon visual inspection
- Invisible deterioration, damage or distress not detected or measured
- Operational performance not measured
- Vulnerability and reliability not adequately addressed

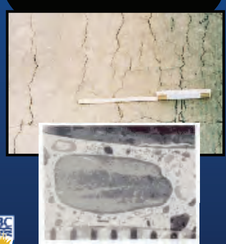
Canadian Research Objectives

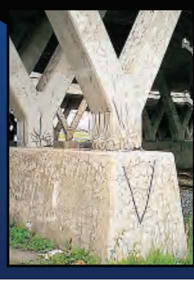
- To improve safety (and security) of concrete bridges through an accurate assessment of bridge condition and performance.
- Develop advanced health monitoring tools based on remote/onsite measurements that are periodic/continuous.
- Relate health monitoring findings to structural condition.
- Use advanced modeling tools to reliably forecast bridge performance, maintenance needs, etc. esp. in the light of impending global warming.

Safety, Security and Sustainability of Bridges: 2 Themes

Materials Health Monitoring (Local)

Structural Health Monitoring (Global)

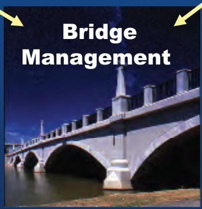




Safety, Security and Sustainability of Bridges: 2 Themes

Theme I
Condition Assessment, Sensing and Modeling for Safety and Security

Materials Health Monitoring



Theme II
Structural Implications

Structural Health Monitoring

We invite you to collaborate with us in finding multi-disciplinary solutions to making infrastructure Safe, Secure and Sustainable

Thank You!